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Departamento de Ambiente e Ordenamento

Catarina Amélia Filipe Miranda

Indoor air quality in classrooms of a school

Qualidade do ar interior em salas de aula de uma escola

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Estagio apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia do Ambiente, realizado sob a orientação científica da Doutora Ana Isabel Miranda, Professora Catedrática do Departamento de Ambiente e Ordenamento da Universidade de Aveiro

O júri

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palavras-chave Qualidade do ar interior, escolas, carpete, re-suspensão, deposição, crianças, saúde

resumo Este trabalho tem como principal objectivo estudar qual o efeito das carpetes na qualidade do ar interior de uma escola primária. Para alcançar este objectivo, as concentrações de PM_{10}, $PM_{2.5}$ e BC foram medidas no interior e exterior da escola. As medições foram em três diferentes períodos em duas salas de aulas onde uma troca entre carpete e piso liso foi realizado. O cálculo da deposição e re-suspensão de partículas, no interior das salas, foi feito através da equação do balanço mássico. A comparação entre o número de partículas, partículas em suspensão e carbono negro também foi realizada.

Existe uma boa relação entre PN e PM (R^2<0.94), pelo que o equipamento Dylos pode ser útil para estudos posteriores, uma vez que é mais económico.

Quando o chão da sala é coberto por uma carpete, os resultados sugerem que os níveis de re-suspensão são mais baixos e os níveis de deposição mais elevados. Desta forma, recomenda-se o uso de carpete dentro da sala de aula para melhorar a qualidade do ar interior.

keywords Indoor air quality, school, carpet cover, resuspension, deposition, children, health

abstract The main purpose of this work is to evaluate the effect of the carpet on the indoor air quality of a primary school. To achieve this goal PM_{10}, $PM_{2.5}$ and BC are measured inside and outside the school. The measurements are performed in two classrooms where an exchange between carpet and regular smooth floor was carried out during three periods. The mass balance equation is used to determinate the resuspension and deposition of particles inside the classrooms. The comparison between particle number, particle matter and black carbon are also performed.

To save money, the Dylos equipment might be useful for further studies. There is a high relation between PN and PM (R^2<0.94).

The results revealed lower resuspension and higher deposition levels when carpet is present in the classroom. Thus, it is recommended to use the carpet inside the classroom.

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List of abbreviations

ACGIH - American Conference of Governmental Industrial Hygienists

AIRMEX - European Indoor Air Monitoring and Exposure Assessment Study

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers

BC - Black carbon

EU - European Union

HESE - Health Effects of School Environment

HITEA - Health Effect of Indoor Pollutants: integrating microbial, toxicological and epidemiological approaches

HVAC - Heating, Ventilation and Air-Conditioning

IAP - Indoor Air Pollution

IAQ - Indoor Air Quality

MB - Mass Balance

NAAQS - National Ambient Air Quality Standards

NIOSH - National Institute for Occupational Safety and Health

OSH Act - Occupational Safety and Health Act

OSHA - Occupational Safety and Health Administration

PM - Particulate matter

PN - Particle number

R^2 - Coefficient of dertermination

RSECE - Regulamento dos Sistemas Energéticos de Climatização em Edifícios

RCCTE - Regulamento das Características de Comportamento Térmico dos Edifícios

SCE - Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios

SEARCH - School Environment and Respiratory Health of Children

SINPHONIE - Schools Indoor Pollution and Health: Observatory Network in Europe.

TLV - Threshold Limit Values

TNO - Nederlandse Organisatie Toegepast Natuurwetenschappelijk Onderzoek

US EPA - United States Environmental Protection Agency

WHO - World Health Organization

1. Introduction

"The risks from air pollution are now far greater than previously thought or understood, particularly for heart disease and strokes. Few risks have a greater impact on global health today than air pollution; the evidence signals the need for concerted action to clean up the air we all breathe" Maria Neira[1].

Recently, the World Health Organization (WHO) published an important study [1] which links annual premature deaths with the air quality. WHO reports that, for the year 2012, around 7 million people died, one in eight of the total global deaths, as consequence of the air pollution exposure. The estimation of deaths related to outdoor and indoor air pollution is 3.7 million and 4.3 million, respectively. The low and middle income countries were the most affected by household air pollution. This is largely due to a high number of people living in homes using wood, coal or dung as primary cooking fuel [2].

In the early 1990's, the U.S. Environmental Protection Agency (US EPA) and its Science Advisory Board ranked indoor air pollution (IAP) among the top five environmental risks to public health (Zhang, 2004). Nowadays, the studies about the negative impacts caused by the indoor air quality (IAQ) are continuously increasing. The research of efficient treatment and prevention to improve IAQ is an important concern for investigators.

Many factors have a large impact on IAQ, namely, heating, Ventilation and Air-Conditioning (HVAC), outside contaminants, human activities and building materials or furnishings. To determine the contribution of the building materials to the IAQ, the composition of the material needs to be looked at along with the amount of material used. Among interior components, the floor represents 15% to 25% of the total surface area, thus the floor covering has a significant contribution for the IAQ (Tremblay *et al.*, 1999).

[1] Dr. Maria Neira: Director of WHO's Department for Public Health, Environmental and Social Determinants of Health

The US EPA has quantified that 70% to 80% of the floors in the United States of America are covered by carpets, which are generally used to improve the thermal and acoustic isolation of the halls. However, during the past few years, the opinion about the effect of the carpet on the IAQ was not consensual. Some studies have shown that carpet is a potential contributor and/or cause of asthma and allergies (e.g. Wilson, 1995; US EPA, 1992). Thus, improvements of the carpet manufacture to minimize its impact on health and improve IAQ are constantly increasing. On the other hand, a few authors (CRI Technical Services, 2003; Tremblay *et al.*, 1999) claim the protective effects of carpet on the human health. The impact of IAQ on human health also depends on the individual characteristic (e.g. age and health problems) being the children particularly vulnerable to the quality of the indoor air. Mendell and Health (2005) claim that poor IAQ at schools, where children spend several hours per day, has a big influence on the performance and attendance of students. The exposure to contaminants may lead children to develop health consequences as they are more susceptible to air pollutants than adults.

In the scope of the cooperation between the Nederlandse Organisatie Toegepast Natuurwetenschappelijk Onderzoek (TNO) and the University of Aveiro, this work aims to evaluate the effect of a carpet on the IAQ of a primary school situated in The Hague, Netherlands. Two classrooms, with the same characteristics were selected for this investigation.

The assessment focuses the particulate matter (PM) and the black carbon (BC) and includes the:

- simulation of the concentration of carbon dioxide (CO_2) to determine the ventilation rate in both classrooms;
- quantification of the concentration of PM, BC and CO_2;
- estimation of the deposition and resuspension of concentration of PM and BC;
- calculation of the settling velocity;
- comparison between PN and PM.

In chapter 2, literature of emission sources of pollutants and health effects of IAQ are reviewed as well as the legal framework on IAQ. Chapter 3 describes the effect of IAQ on children´s health, with a particular focus on the impact of a carpet´s cover inside a room. The study case is described in the chapter 4, which includes the selection of the primary school and classrooms. Ventilation systems and the experimental work are explained as well in chapter 4. The description of processing data and results of resuspension and deposition of PM and BC can be found in chapter 5. The relation between particle number and PM levels are shown. Finally, chapter 6 gives conclusions about the carpet´s impact on the IAQ. It is also discusses the limitations of the work.

2. Indoor air quality

Generally, the concerns related to the effects of air quality on public health were initially related to outdoor air pollution. However, early in the 1970's, due to the energy crisis, the concept of IAQ emerged. Focused on the aesthetic, lower cost, noise and ventilation control, the new construction's design was based on sealed buildings. With a low level of air exchange between inside and outside, the concentration of indoor air pollutants increased, having thus higher concentrations than outside (Schirmer *et al.*, 2011; Pegas *et al.*, 2011a). Since then, a high and persistent number of health and discomfort complaints from building occupants started to appear. Any specific illness or cause could not be identified however the effects seemed to be linked to the time spent inside a building. These complains were found to be withdrawn after the occupants moved from the building. In 1984, the WHO named this occurrence 'sick building syndrome' and suggested that up to 30% of the new buildings in the worldwide may be the subject of excessive complaints related to IAQ (US EPA, 1991).

Indoor levels of many pollutants can be two to five times higher than outdoor levels (Kotzias, 2005; Pegas *et al.*, 2011; US EPA, 1989). Once people spend in average 90% of their daily time inside a building (Eurostat, 2004), their exposure to high concentrations of pollutants can have a negative impact on their health. In fact, IAQ is strongly related with a decrease of the productivity, comfort, health and welfare (Austin *et al.*, 2002; Martínez and Callejo, 2006). Thus, to solve these problems, a good understanding and knowledge about IAQ is required. Along this chapter IAQ pollutant sources, health effects, indoor-outdoor relationship and legislation are discussed.

2.1 Emission sources, pollutants and health effects

Due to the variety of pollutants in the air, identifying the exact source of indoor air contaminants inside homes and buildings is difficult. They are emitted by many sources such as open fires, HVAC system, building materials, furniture, asbestos-containing insulation and cleaning products. Outdoor air pollutants can be also transported to indoor. Figure 1 illustrates several sources of indoor air pollution.

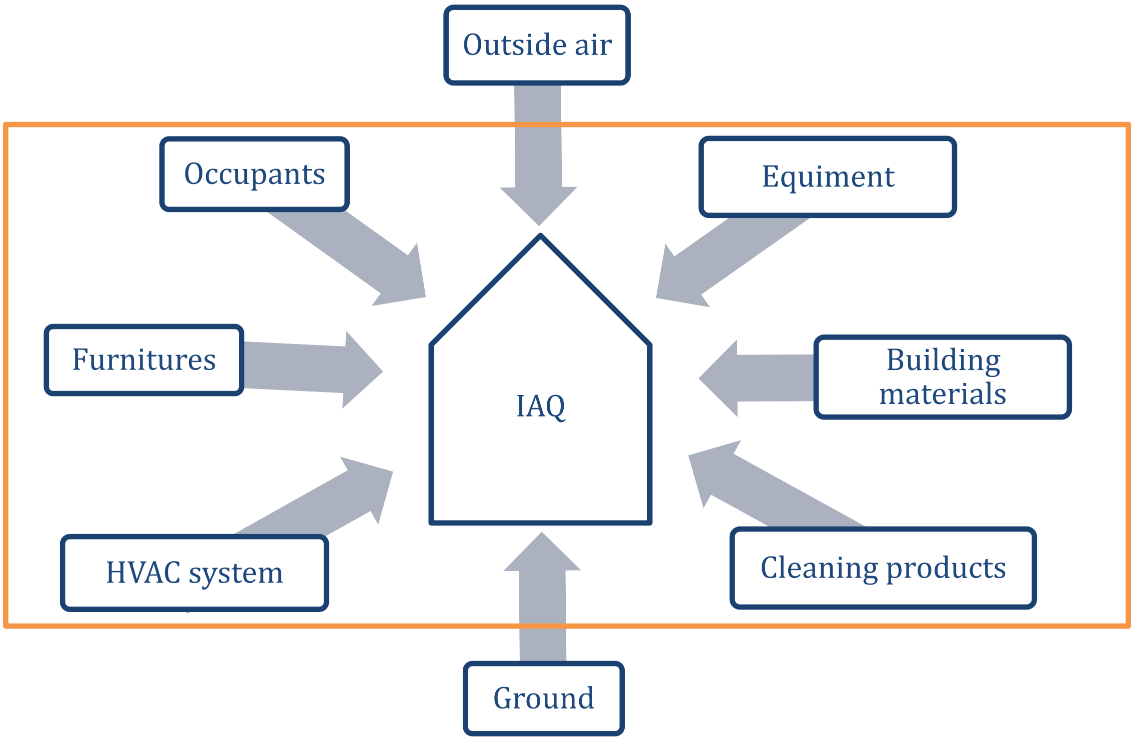


Figure 1: Schematic diagram showing the factors which affect the IAQ.

Some sources, such as furniture and building materials, release pollutants continuously. Other sources related to activities carried out at home (smoking, use of solvent for cleaning, etc.) emit pollutants intermittently. High pollutant concentrations remain in the air for long periods after some of those activities finish [3] [4].

The main factors which are responsible for the inside concentration of pollutants depend on their emission rates, flow rate of fresh air, characteristics of new air, maintenance of the ventilation system and concentration of outside pollutants (Campos and Santos, 2010). This latest enters and leaves the building by three different mechanisms: infiltration, natural ventilation, and mechanical ventilation.

Figure 2 shows the pathways of outdoor particles in an indoor environment (Chen and Zhao, 2011).

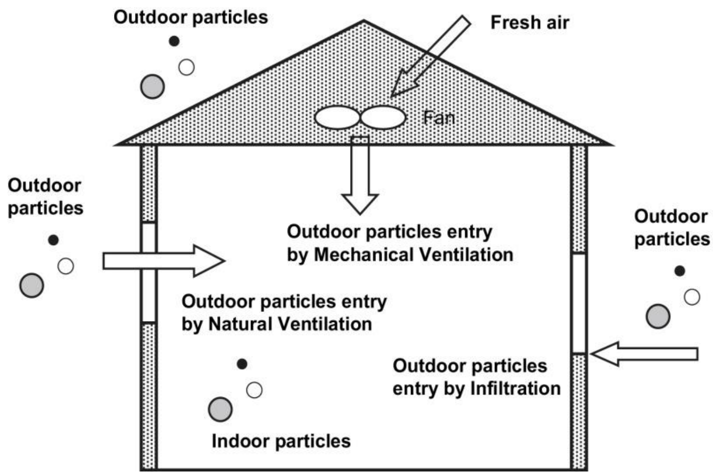


Figure 2: Pathways of outdoor particles in an indoor environment (source: Chen and Zhao, 2011).

The infiltration process implies that outdoor air flows into the house through openings, cracks in walls, joints, floors, ceilings and around doors and windows. In natural ventilation, the air moves through opened windows and doors. The air movement associated with infiltration and natural ventilation is caused by air temperature differences between indoors and outdoors and by wind. Finally, there are a number of mechanical ventilation devices, from outdoor-vented fans that intermittently remove air from a single room, such as bathrooms and kitchen, to air handling systems that use fans and duct work to continuously remove indoor air and distribute filtered and conditioned outdoor air to strategic points throughout the house. When there is little infiltration, natural ventilation, or mechanical ventilation, the air exchange rate is low and pollutant levels can increase.

Moreover, the factors affecting IAQ, such as those presented in Figure 1, are classified in four different types (TSI, 2013):

- physical - temperature, humidity and HVAC system;
- particles and aerosols - solids or liquids light enough to be suspended in air;
- chemical - cleaners, solvents and fuels;

- biological - bacteria, fungi, viruses and molds.

Furthermore, particles are classified in three general categories: coarse (PM_{10}), fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$). They are derived from dust, construction activities, printing, photocopying, manufacturing processes, smoking, combustion and some chemical reactions in which vapours condense to form particles. These are categorized as dust, smoke, mist, fume and condensates. The adhesives, various combustion by-products, emissions from furnishings, floor and wall coverings are typical examples of airborne chemicals. Examples of common biological pollutants that can impact air quality are pollen, animal hair, dander and excrement.

In general, people who are most susceptible to the adverse effects of pollution (*e.g.*, the very young, elders, people with cardiovascular or respiratory disease) tend to spend even more time indoors (US EPA, 1997). However, the symptoms caused by indoor air pollutants on the health vary according to an individual´s sensitivity and length of exposure. A more detailed relationship between pollutants and health impact is presented in Table 1 (Campos and Santos, 2010; Martínez and Callejo, 2006; WHO, 2010a).

Table 1: Relationship between indoor pollutants, sources and health effect.

Pollutant	Main sources	Health effect
Carbon monoxide (CO)	Combustion processes, tobacco smoke, vehicle exhaust.	Headaches, nausea, tiredness and dizziness, effects on the central nervous system and cardiovascular system.
Carbon dioxide (CO_2)	Breathing and body odours, traffic, industry, tobacco smoke.	Headaches, tiredness, breathlessness, effects on the central nervous system and cardiovascular system, irritation of eyes and throat.
Particles (PM)	Traffic, industrial sector civil works, dust, combustion processes, HVAC system, tobacco smoke.	Dry eyes, breathing problems, asthma and allergy, irritation of nose, throat and skin, coughing and sneezing.
Ozone (O_3)	Photocopiers and laser printers, cleaning equipment, photochemical reactions, disinfectant of water.	Breathing problems, eyes irritation, headaches, alterations of surveillance and action, oedema if the exposure was prolonged or repeated, asthmatic and allergic reactions, dry mouth and throat , chest tightness and coughing.

Volatile Organic Compounds (COV)	Solvents, paints, glues, resins and varnishes, cleaning products, cork agglomerates, disinfectants, deodorants, perfumes, insecticide, pesticides and fungicides, construction material furniture, tobacco smoke.	Symptoms of allergy, nausea, leukemia, skin and lung cancer, dryness of mucous of the nose and throat, headaches, fatigue and dizziness.
Nitrogen dioxide (NO_2)	Combustion processes.	Breathing problems, eyes and throat irritation, cough and fatigue, chronic bronchitis.
Formaldehyde (HCHO)	Disinfectants, pesticides, wood products, foam insulation, construction material, furniture, insulating adhesive glues and inks, tobacco smoke, textile, lacquers solvents and resins.	Eyes, nose, throat and skin irritation, breathing problems, headaches, sickness, fatigue.
Radon (Rn)	Granitic soils and construction materials.	Increased risk of lung cancer.
Naphthalene ($C_{10}H_8$)	Tobacco smoke and naphthalene.	Eyes and breath system irritation.
Bacteria, fungi, legionella	HVAC system, construction materials and decoration, carpets, humid zones of buildings, pollen, hair, feathers, insect excrement, occupants, supply air and ditch-water.	Rhinitis, sinusitis and asthma, tuberculosis, pneumonia, cryptococcosis, eyes, nose, throat and skin irritation, headaches, fever, fatigue and muscle aches, legionnaires disease and pontiac fever.

The effect of IAQ on the health range from short-term effects (eye, nose and throat irritation, headaches, allergic skin reaction, nausea dizziness, fatigue, among others) to long-term effects (damage to the heart, liver, and central nervous system and cancer) (TSI, 2013). Thus, the necessity of a legal framework is essential.

2.2 Legal Framework

To protect and minimize the impact of IAQ on the human health, different guidelines were made. Their main goal is to establish threshold values of pollutants to preserve a good and safe IAQ. Due to the different activities inside buildings, guidelines specifically addressing the security and heath in industrial environment were delivered as well as guidelines for general IAQ.

2.2.1 Occupational security and health

In the United States of America, the Occupational Safety and Health Act (OSH Act) of 1970 was created to prevent workers from being killed or seriously harmed at work. This law created the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH). The OSHA sets and enforces protective workplace safety and health standards about ventilation and air contaminants that can be involved on IAQ. These standards were developed through a formal rulemaking process which limits only can be changed by reopening this process [5] [6]. NIOSH is the federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness [7]. NIOSH recommended safe levels of exposures to toxic materials, harmful physical agents and substances for industrial environments. However, these recommendations are rarely reviewed.

The American Council of Governmental Industrial Hygienists (ACGIH) is a member-based organisation dedicated to the occupational health, industrial hygiene and safety industries. In 1968, ACGIH developed Threshold Limit Values (TLVs) for 400 hazardous substances. The TLVs are based on 8 hour time-weighted-average that suggested limits for working day exposure. These guidelines were updated in 1999 and were established to protect the most sensitive people. They are intended for application to indoor and outdoor exposures, but are guidelines rather than an enforceable standard.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) aims to advance the arts and sciences of heating, ventilating, air conditioning and refrigerating to serve humanity and promote a sustainable world. ASHRAE developed two promulgated standards "Ventilation for Acceptable Indoor Air Quality" (ASHRAE 62-2001) and "Thermal Environmental Conditions for Human Occupancy" (ASHRAE 55-2004). Those standards are not only used in the USA but also in other areas of the world (ASHRAE *et al.,* 2011; Jakob *et al.*, 2004; Kohloss *et al*., 2004; Martínez and Callejo, 2006).

A summary of the occupational IAQ guidelines for some pollutants is shown in Table 2.

Table 2: Summary of occupational IAQ guidelines.

Chemical parameters	OSHA	NIOSH	ACGIH	ASHRAE
PM_{10} (mg/m^3)	15 (8h)		10 (10h)	0.15 [1]
$PM_{2.5}$ (mg/m^3)	-	-	3 (10h)	0.035 (24h)
CO_2 (ppm)	5000 (8h)	3000 (0.25h)	5000 (10h) 3000 (0.25h)	1000 [1]
CO (ppm)	50 (8h)	35 (8h)	25 (10h)	9 [1]
O_3 (ppm)	0.1 (8h)	0.1 (8h)	0.05 (heavy work) 0.08 (moderate work) 0.1 (light work) 0.2 (any work 2h)	0.075 (8h)
Formaldehyde (ppm)	0.75 (8h)	0.016 0.1 (0.25h)	0.3 (10h)	0.75 (8h) 2 (0.25h)
Biological parameters				
Bacteria (UFC/m^3)	-	-	500	-
Fungi	-	-		-
Legionella (UFC/l)	-	-	100	-

[1] maximum values

The OSHA standard level is based on an eight-hour time-weighted average and is an enforced standard that must not be exceeded during any eight-hour work shift of a 40-hour work week. ACGIH standard is a recommended time-weighted average upper limit exposure concentration for normal eight to 10-hour workday and 40-hour work week.

Comparing the OSHA with ACGIH guidelines the values are similar, however the OSHA does not have values for the biological parameters and for $PM_{2.5}$. The NIOSH guideline shows lower values for formaldehyde and the ASHRAE has lower levels of PM, CO_2, CO and O_3.

2.2.2 Indoor Air

WHO presented in 2010 the first time evidence and guidance to protect health globally from the impact of indoor chemicals. The guidelines recommend targets for indoor air quality which the health risks are significantly reduced and provide a scientific basis for legally enforceable standards in all regions of the world (WHO, 2010b).

The National Ambient Air Quality Standards (NAAQS) for wide-spread pollutants from numerous and diverse sources considered harmful to public health and the environment [8]. The concentrations are set conservatively in order to protect the most sensitive populations such as asthmatics children and the elderly [9] [10].

Within the existent policies of the European Union, a common policy for the European Commission (EC) about IAQ is still not available. However, Table 3 shows few directives of the European legislation which include aspects of indoor are quality. Nevertheless, these are not fixed or establish any limit values.

Table 3: EU Directives which include aspects of indoor are quality.

Directives	Designation	Description
1989/106/CEE 21 December	Building construction products directive	Ensures the free circulation of construction products in the European Union (EU) by harmonizing national legislation in the field of essential health, safety and well-being applicable to these products.
1990/396/CEE 29 June	Gas applications directive	Defines essential requirements for the manufacture, installation and operation of gas appliances.
1991/689/CEE 12 December	Hazardous waste directive	Establishes conditions for handling, recovery, transport and disposal for hazardous waste.
1992/42/CEE 21 May	Heat applications directive	Establishes requirements for the performance for new hot water boilers fed with liquid or gaseous fuels.
2001/95/CE 3 December	General safety products directive	Ensures the safety of products placed on the market.
2005/32/CE 3 December	Eco-Design directive	Sets community eco-design requirements for energy-using products with the aim to ensure the free movement of these products within the internal market.
2006/32/CE 5 April	Energy end-use efficiency and energy services directive	Encourage the cost-effective relation of end-use energy improvement in Member States, through the establishment of indicative targets as well as mechanisms, incentives and institutional frameworks, financial and legal, required to remove the current deficiencies and market obstacles which prevent an efficient end-use energy, creating development conditions, promotion of a market for energy services and for the development of other measures to improve energy efficiency for end consumers.
2002/91/CE 16 December	Energy performance of buildings directive	Establishes requirements for the methodology to calculate the integrated energetic performance of buildings, energy certification of buildings and regular inspection of boilers and air conditioning systems in buildings. Defines and applies the minimum requirements for the energy performance of new buildings and for existing buildings undergoing a major renovation.
2010/31/EU 19 May		Reformulation of the original energy performance of buildings directive and new challenges.

The Directive 2002/91/CE in particular, reports that measurements to improve the energy performance should take into account the indoor environment. In Portugal this directive was transposed in 2006 into three national legislations:

- 78/2006- National Energetic Certification System and Indoor Air Quality in Buildings (Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios - SCE);
- 79/2006- Energetic System of Climate Regulation in Buildings (Regulamento dos Sistemas Energéticos de Climatização em Edifícios - RSECE);
- 80/2006- Characteristics of Thermal comportment Regulation in Buildings (Regulamento das Características de Comportamento Térmico dos Edifícios – RCCTE).

In 2013, the RSECE has been updated by Portaria n.º 353-A/2013. This latest sets the physical, chemical and biological parameters but also the minimum value of ventilation per person or per area. The values of the maximum concentration are based on 8 hours of exposure.

Other countries also have their own IAQ framework, such as France, Sweden, Norway, Finland, Netherlands, Romania, Slovenia, Canada, China and Australia. Table 4 shows the standard values established by WHO and different countries in the world.

Table 4: IAQ standard values established by the WHO and in different countries in the world.

Chemical parameters	WHO	Portugal	France	Sweden	Norway	Finland	Netherlands	Romany	Slovenia	Canada	China	Australia
PM_{10} (µg/m³)		50			50	20	40			150	90	100
$PM_{2.5}$ (mg/m³)		0.025										
NO_2 (µg/m³)	200 [4] 40 [3]			470 (1h)	40	40		100 (1h)		240 (1h)		
CO_2 (ppm)		2250 mg/m³			1000	1200			1670	3500 (8h)	1800 (8h)	
CO (mg/m³)	7 [4] 10 (8h) 35 (1h) 100 (0.25h)	10	23-57	2	10 (8h)	8		6 (0.5h)	10	12.6 (8h)	10 (1h)	10 (8h)
O_3 (mg/m³)	0.12 (8h)	0.2	0.11 (8h) 0.24 [6]	0.05								
Formaldehyde (mg/m³)	0.1 (0.5h)	0.1	0.1 [1] 0.03 [2]		0.1 (0.5h)	0.05		0.035 (0.5h)	0.1		0.122	0.12
VOC (mg/m³)		0.6										
Radon (Bq/m³)	100	400	400	200	100	200 [3]		140	400		400 [3]	200
Biological parameters												
Bacteria (UFC/m³)		350										
Fungi (UFC/m³)		500										
Legionella (UFC / l)		100										

[1] reference value [2] immediate action value [3] annual average [4] daily average [5] maximum instantaneous [6] hourly maximum

The limits of PM_{10}, NO_2 and CO_2 of Canada, China and Australia are higher when compared with the European countries and WHO. Norway and Finland show lower values of pollutants. Portugal shows a more complete IAQ framework, having additional levels of $PM_{2.5}$. Netherlands only has limit value for PM_{10}. However, some of the recommended values are not associated with any time limit.

3. IAQ effects on children´s health

Children spend most of their time at school and therefore it is important to know how IAQ can affect their health. Moreover, it is interesting to investigate the impact of carpets used as covering floor in primary schools.

3.1 IAQ in schools

Poor indoor environments in schools cause health effects that directly impair attentiveness, memory (e.g. neurologic effects) and indirectly affect learning. For instance, indoor pollutants might exacerbate diseases such as asthma or allergies resulting in students being absent from school. In turn this can impair learning, or lead to use of medications that impair performance (Mendell and Heath, 2005). This occurrence is related to the fact that (Bayer *et al.*, 2000):

- their tissue and organs are growing;
- they breathe higher volumes of air comparatively to their body weights;
- they spend most of their time inside;
- their lungs are immature and the tissues are not totally developed;
- they do not control the environment that they occupy.

Studies about IAQ in European schools were performed by the Health Effects of School Environment (HESE) group (HESE, 2006), showing that wicked ventilation is a common problem. Other causes for a poor IAQ in schools are inadequate function and maintenance of installation related to financial problems and the high number of students per classroom (Mendell and Heath, 2005; Almeida *et al.*, 2011). Lee and Chang (2000) evaluated the levels of pollutants on five schools in Hong Kong. The levels of PM_{10} and CO_2 were few times higher than the maximum recommended values (Lee and Chang, 2000). The PM_{10} values were compared to the Hong Kong Special Administrative Region (HKAQO) standards (Hong Kong Special Administrative Region, 2003) and the CO_2 level with the ASHRAE guidelines. Other international studies about childrens health in schools are performed in the following projects:

- HITEA - Health Effect of Indoor Pollutants: integrating microbial, toxicological and epidemiological approaches;
- SEARCH - School Environment and Respiratory Health of Children;
- AIRMEX - European Indoor Air Monitoring and Exposure Assessment Study;
- SINPHONIE - Schools Indoor Pollution and Health: Observatory Network in Europe.

The HITEA identified the role of indoor biological agents in the development of long term inflammatory, respiratory and allergic health impacts among children [11]. The SEARCH project assessed the associations between the schools environment and child respiratory health and gives recommendations to improve the quality of the schools environment [12]. The AIRMEX project evaluated the relationship between indoor air pollution and human exposure focused on public building, including schools and kindergartens [13]. SINPHONIE connected 38 institutions from 25 countries (among them the University of Aveiro) aiming to gather information about the IAQ in European schools and the health of children. This project provided a set of good practice and recommendations about IAQ in schools highlighting children, parents and teachers about the importance of a good IAQ [14].

In Portugal, the SaudAr project measured, in four schools of Viseu, higher PM_{10} concentrations during winter time, when compared with the legal framework. It also refers that children living in the urban area were more exposed to PM_{10} and children living in the suburban area more exposed to O_3, VOCs and NO_2 (Borrego et al. 2008). Silva (2010) measured higher PM_{10} concentration values inside the classrooms of two primary schools than outside.

In 2011, another study (Pegas *et al.*, 2011) that evaluated the indoor and outdoor school levels of pollutants, measured a higher indoor concentration of CO_2, caused by bacteria and fungi, traffic emissions and inside sources (e.g., building materials, cleaning products and floor covering).

In summary, the studies about IAQ in schools showed a higher concentration levels inside than outside. Thus, it is important to minimize high concentrations of pollutants in classrooms.

3.2 Carpet's effect

Floor covering, which varies between 15 to 25% of the surface area of a classroom, have an important influence on indoor environments. As previously mentioned, using carpets as covering floor shows some benefits, such as comfort, acoustic insulation, safety (no-slip surface), isolation, save energy and low-cost. For instance Mihrshahi et al. (2002) concluded that carpets are effective in reducing exposure to dust mite allergen.

Alan Hedge (2001), professor of design and environmental analyse at Cornell University, shows that carpets do not contribute for respiratory problems (i.e. allergies and asthma) in schools. Carpets can even improve the IAQ by trapping contaminants and allergens, as long schools keep floors clean and use high-efficiency microfiltration vacuum bags. The recommendation is to combine the strengths and benefits of carpeting (for areas under desks and where the teaching activities occur) and smooth floors (around wet sink areas and shoes storage) [15].

The Research Triangle Institute and the University of North Carolina made a study (Foarde and Berry, 2004) about the bio-contaminant levels associated with carpeted and hard surface flooring in two schools. The results show that carpet flooring was not the major contributor to airborne levels of bio-contaminants in these two schools. Other studies also show the positive effect of using carpets in IAQ of schools (CRI Technical Services, 2003; Tremblay *et al*., 1999; Bates, 2011).

The deposition and resuspension levels of pollutants, in particularly PM, are important factors when the floor covering is studied. Some studies focused on the relation between the deposition rate and the floor covering, describing this latest as a potential filter of particles. However, the deposition rates of particles vary with the particle size. For particles sizes larger than 1 μm the gravitation is dominant. For particles sizes smaller than 0.1 μm, the diffusion is dominant and for particles sizes between 0.1 and 1 μm a mixture of both mechanisms may be assumed (Lai, 2004). Afshari et al. (2008) found that the amount of carpet was significantly correlated with particle deposition.

Wang (2012) has shown, for a room with carpet covering, a lower deposition for small particles (0.723 to 1.382 μm) due to a weak gravitational settling. Nevertheless, the bigger particles (<4.068 μm) have a higher deposition rate because of the gravitational settling effects (Wang, 2012).

Namely when carpets are used, the calculation of the amount of deposited or re-suspended particles in a room may be based on the Mass Balance (MB) equation:

$$V\frac{dC_{in}}{dt} = QC_{out} + E - QC_{in} - D \qquad \text{equation 1}$$

where:

C_{in} – Inside concentration (mg/m^3)

C_{out} – Outside concentration (mg/m^3)

t – Time (h)

E – Emission flow rate of pollutant (mg/h)

D – Deposition flow rate of pollutant (mg/h)

Q – Ventilation rate (m^3/h)

V- Volume (m^3)

Solving the MB differential equation (eq.1), the C_{in} values are calculated by the equation 2.

$$C_{in} = C_{out} + (1 - e^{-\frac{t}{\tau}})\left(\frac{E}{Q} - \frac{D}{Q}\right) \qquad \text{equation 2}$$

With $$\tau = \frac{V}{Q} \qquad \text{equation 3}$$

τ – Average air residence time in a room (h)

Based on equation 2 it is possible to calculate the deposition and resuspension levels assuming a zero emission rate and a zero deposition rate, respectively. Therefor the equations to calculate the deposition and resuspension are represented:

$$\frac{D}{Q} = -\frac{C_{in}-C_{out}}{(1-e^{-\frac{t}{\tau}})} \qquad \text{equation 4}$$

$$\frac{E}{Q} = \frac{C_{in}-C_{out}}{(1-e^{-\frac{t}{\tau}})} \qquad \text{equation 5}$$

Where:

E/Q – Resuspension level (mg/m^3)

D/Q – Deposition level (mg/m^3)

In summary, to calculate deposition and resuspension of particles and assess their contribution to IAQ, the following is needed:

- inside and outside concentration;
- ventilation rate;
- volume of classroom.

4. Study case

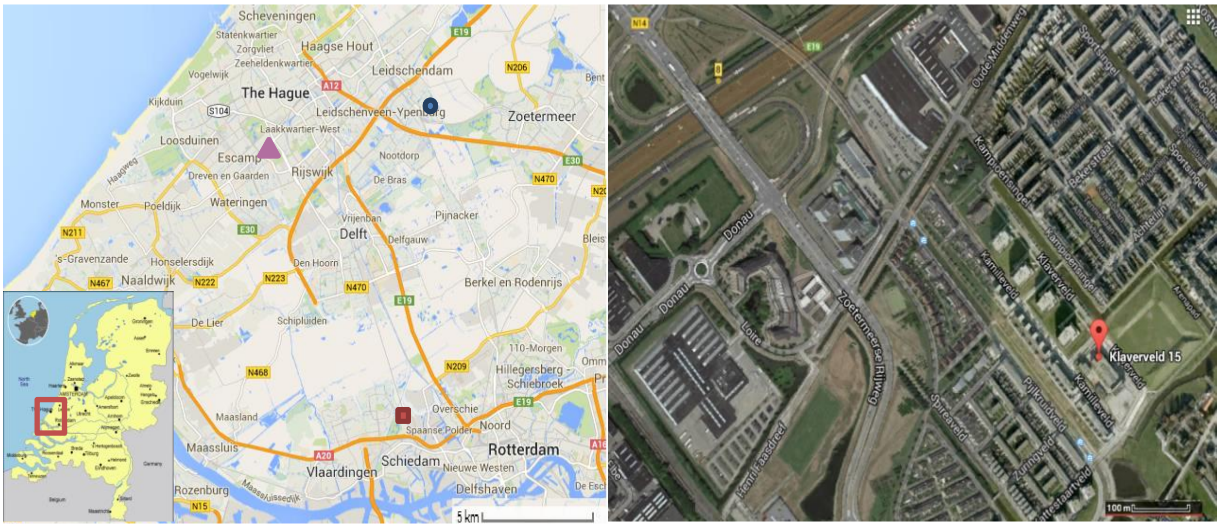
The aim of the study case was to evaluate the carpet´s effect on the IAQ. The followed criteria for the selection of the primary school were:

- the children stay inside the room as much as possible;
- the school needs to be near a road, thus the concentration related to the movement of fine dust is as high as possible;
- same characteristics between the two classrooms (e.g. area, activities, board, furniture, etc.);
- same number of children in the classrooms;
- children need to have the similar age;
- ventilation with unfiltered air;
- classrooms need to have the inlet of ventilation on the same side of the building.

After an examination of three different primary schools, two of them were more adequate for this study. However, one school used filtered ventilation. Therefore, the "Balans" school presented all required characteristics above mentioned. The experimental campaign was performed between the 27 May and the 3 July (2013), along three different periods.

4.1 School description

The *Balans* school is a primary school founded in 1999 and is frequented by 680 students. It is located in the Netherlands in surrounding of The Hague, a city with more than 500.000 inhabitants. More specifically, it is situated in Leidschenveen-Ypenburg, a vinex-location of The Hague with 47.000 inhabitants, as shown in the Figure 3.



● Balans School ▲ Monitoring station The Hague ● Monitoring station Schiedam

Figure 3: Location of the primary school ´Balans´.

The school is surrounded by houses, roads, cycle paths, tram line and the highway "A4". Figure 4a and 4b shows the street view and the front side of the school.

Figure 4: a) Street view of the school; b) Front side of the school.

The school opens at 08h00 and finishes at 15h00, having a lunch break of one hour at 12h00. The ages of the children are between five to twelve years old. They have physical education two times per week outside the school.

4.1.1 Characteristics of the classrooms

The two selected classrooms are "5B" and "6A". Both are situated on the same side of the building, with a North-East orientation and both have a digital board (Figure 5). The main characteristics of the classrooms are listed more in detail in Table 5.

Figure 5: The inside classroom with a digital board.

Table 5: Characteristics of the two classrooms.

		Classroom 5B	Classroom 6A
Number of children		30	30
Age (years old)		10	10
Room area (m^2)		48	48
Volume (m^3)		62.5	62.5
Dimensions	Width (m)	5	5
	Length (m)	5	5
	Height (m)	2.5	2.5

The characteristics of the two classrooms are equal and the number and age of children are the similar.

An important factor for this study is the ventilation system. The Balans school has three different types of ventilation systems, namely: ventilation grill in windows, ventilation grill in doors and HVAC system. Figure 6 and 7 shows the three ventilations systems.

Figure 6: Ventilation systems: a) grill in windows; b) grill in door.

Figure 7: HVAC system.

The grill system was closed during the monitoring period to avoid exchange of air particles with the corridor. Thus, the window grill is the main source of particle infiltration because it do not have air filters.

The HVAC system extracts the air from the classrooms. Figure 8 illustrates the in- and out flow of air.

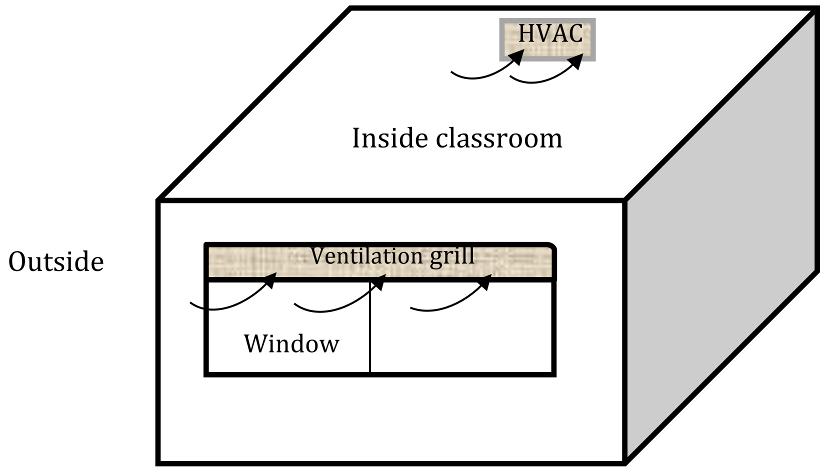


Figure 8: Ventilation system of the classroom.

The Dutch norm NEN NPR 1090 establishes ventilation values for the indoor environments. The flow rate of the ventilation per child needs to be 5.5 dm^3/s and 10 dm^3/s per adult. Thus, for 30 children and one teacher a ventilation rate of 155 dm^3/s is required. On 5 June 2013 a verification of the ventilation rate was made for the classrooms. The measured values were different and thus an adjustment of the ventilation rate was made. The values before and after the adjustment are shown in Table 6.

Table 6: Ventilation rate values.

	Ventilation rate [dm^3/s]	
Classroom	Until 5 June 2013	After 5 June 2013
5B	170	153
6A	155	155

In order to compare and evaluate the effect of the carpet cover, this adjustment is necessary to maintain an equal inflow of particles for both classrooms.

4.2 Experimental work

To determine the deposition and resuspenstion in the carpet, the concentration of PM_{10}, $PM_{2.5}$ and BC are measured inside and outside the school. Furthermore the CO_2 and the Particle Number (PN) concentration are measured inside the school.

4.2.1 Inside measurement

To evaluate the carpet's impact on the IAQ, the monitoring time was divided in three different periods. First period, both rooms had a regular smooth floor. During the second period, classroom 6A was equipped with a carpet and the 5B kept the smooth floor. Finally, the third period, 5B had a carpet and 6A had the regular smooth floor. Table 7 summarises these three monitoring periods.

Table 7: Schedule of the three monitoring periods.

	Date	Classroom 5B	Classroom 6A
Period 1	27 May – 5 June	Smooth floor	Smooth floor
Period 2	6 June – 19 June	Smooth floor	Carpet
Period 3	20 June – 3 July	Carpet	Smooth floor

All measurements are performed by TNO´s equipments. Figure 9 shows a picture of the installed equipment by TNO, inside the classroom.

Figure 9: Equipment used during the monitoring period.

The main characteristic of the equipment used for the measurements of the pollutants are shown in Table 8.

Table 8: Equipment used for the monitoring.

	Equipment used	Characteristic
Particulate matter (PM)	Grimm fine dust monitor type: 265 and 180	Continuously and simultaneously reports PM_{10}, $PM_{2.5}$ and PM_1 in mg/m^3. It measures every 5 min.
Black carbon (BC)	Multi Angle Absorption photometer (MAAP) type: 5012	Operates at 670 nm with a constant sample flow rate (1000 dm^3/h) controlled by a variable speed pump and recording of the actual sample flow, report BC every 5 min.
Dioxide carbon (CO_2)	Sensors Europe S-AGM plus/1030	Measures continuously and simultaneously CO_2, gives a fast response time (5 to 45 s).
Particle number (PN)	Dylos	Laser particle counter with 2 size ranges (>0.5 and >2.5 μm). It measures every 5 min.
Window/door opening time	Reed relay	Gives value in percentage of opening time of window and door, during a 30 min average.

The measured PN values are related to the PM values. If there is a relation, it is possible to use only PN measurements for further studies. This, because Dylos equipment is cheaper than PM equipment.

The flow rate inside the classroom is influenced by the behavior of the occupants. Therefore the Reed relay is used to measure the time that windows and doors were open.

4.2.2 Outside measurement

The outside monitoring consisted in the measurement of PM_{10}, $PM_{2.5}$ and BC. The APS (model 3321) is used to measure the PM. It measures particles between 0.5 and 20 µm (real time dynamic) and deliver 5 minutes averages concentration values. The used BC equipment was equal to the inside equipment (see MAAP, Table 8). Both were measuring continuously giving an average concentration value every 5 minutes. Figure 10 shows a picture of the equipment used for the outside measurements.

Figure 10: Equipment used on the roof of the school.

Table 9 shows a summary of the inside and outside pollutants measured during the monitoring period. The data treatment and results of this work are discussed in the following chapter.

Table 9: Summary of the inside and outside measurements.

		PM_{10}	$PM_{2.5}$	PN	BC	CO_2	Ventilation rate
Inside (classrooms)	5B	✔	✔	✔	✔	✔	✔
	6A	✔	✔	✔	✔	✔	✔
Outside (roof)		✔	✔	-	✔	-	-

5. Processes and analysis of results

This chapter describes the data treatment and analyses of the results. It focuses on PM_{10}, $PM_{2.5}$, BC and CO_2 concentration values measured during the experimental work. Moreover, ventilation rates were calculated to determine the resuspension and deposition of PM_{10}, $PM_{2.5}$ and BC. Figure 11 shows a scheme of the adopted methodology which is based on equation 4 and 5, derived from the MB equation.

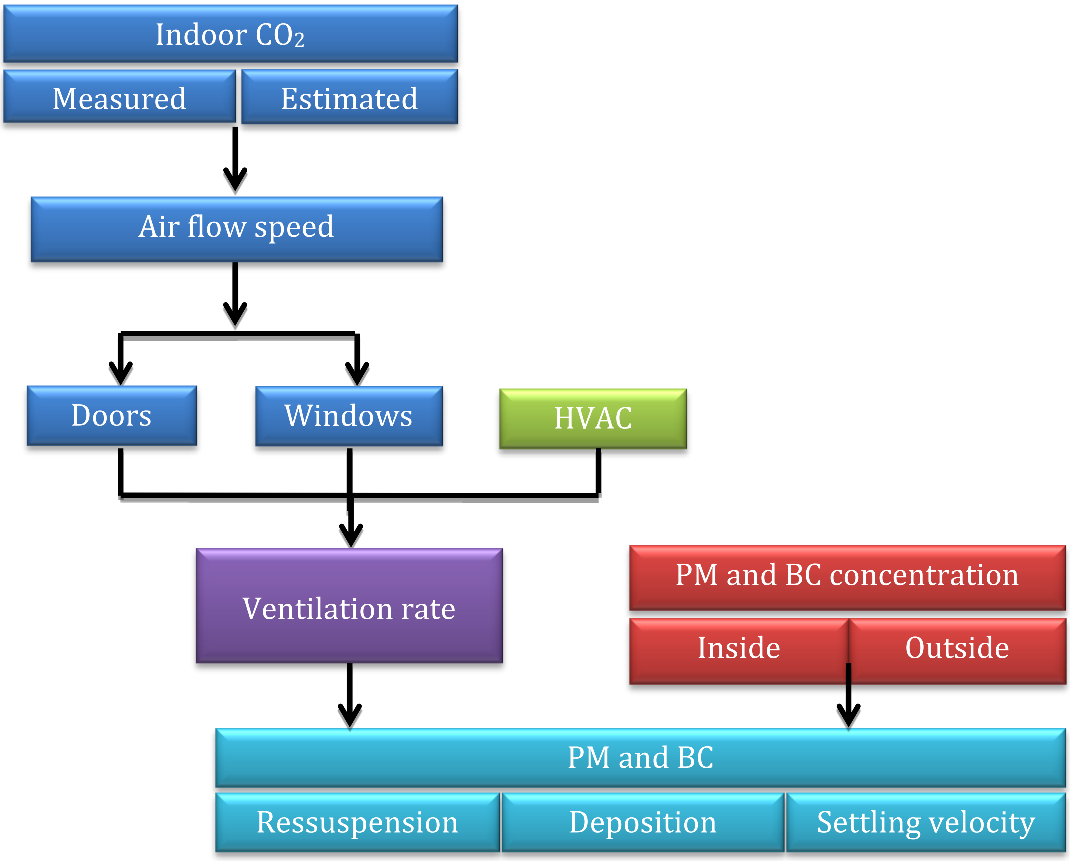


Figure 11: Schematic overview of used methodology to determine the resuspension, deposition and settling velocity.

As there is no activity during the weekends and holidays the data were excluded from the data treatment process. The covering floor was changed on Wednesday (5 and 19 June). Thus, the two following days after this changes no measurements are processed to get a stabile room condition.

5.1 Ventilation

The effect of opening the door and windows – measured by the Reed relay – results in the necessity of new calculations of ventilation rates for the classrooms.

Classrooms are considered as well-mixed zones.

5.1.1 Methodology

To determine the new ventilation rate, three elements are needed:

- simulation of CO_2;
- flow rate coming from the open door;
- flow rate coming from the open windows.

To calculate the flow rate (equation 6), it is needed to know three parameters:

- the area of the door/windows;
- air flow speed;
- the percentage of the time that doors and windows are open.

$$Q = A \times v \times \% \qquad \text{equation 6}$$

Where:

Q – Flow rate (m^3/h)

A – Area (m^2)

v – Air flow speed (m/h)

% – Percentage of time of opening door/window (%)

The final average ventilation rate for each classroom and monitoring period is calculated by equation 7.

$$Q = Q_{door} + Q_{window} + Q_{HVAC} \qquad \text{equation 7}$$

The air flow speed is not measured during the experimental work. Thus, the determination of this parameter is made by attributing a value. This value is estimated based on the comparison between the CO_2 measurements and the estimated CO_2 values through the MB equation.

The estimated CO_2 values are related to the emission of breathing by the occupants, because it is the only source of CO_2 inside the classrooms. Table 10 shows the values of the used emission rate.

Table 10: Emission flow rate of CO_2 by the breath of the occupants.

nº person	Age	CO_2 [l/h]
1 child	10	14
1 teacher	adult	19

Equation 8 is used to convert the emission flow rate of CO_2 by the breath the occupants to mass flow rate (g/h).

$$P_{CO2} = C_P \times n \times M \qquad \text{equation 8}$$

With,

$$n = \frac{P \times V}{R \times T} \qquad \text{equation 9}$$

Where:

P_{CO2} – Mass flow of CO_2 emitted by the breath (g/h)

C_p – Volume flow of CO_2 emitted by the breath (l/h)

n – Number of moles in 1l of air (mol/l)

M – Molar mass (28.96 g/mol)

P – Atmospheric Pressure (Pa)

V – Volume (m^3)

R – Ideal gas constant (8.314 J mol^{-1} K^{-1})

T – Temperature (K)

To estimate the indoor CO_2 levels, the MB equation (eq. 1) is solved without the deposition, resulting in equation 10.

The solution of the differential equation (eq. 3) is:

$$C_{in} = C_{out} + \left(1 - e^{-\frac{t}{\tau}}\right)\left(\frac{E}{Q}\right) \qquad \text{equation 10}$$

With, $$\tau = \frac{V}{Q} \qquad \text{equation 11}$$

Where:

C_{in} – Inside concentration (mg/m³)

C_{out} – Outside concentration (mg/m³)

t – Time (h)

E – CO_2 emission flow rate (g/h)

Q – Ventilation rate (m³/h)

V – Volume (m³)

τ – Average air residence time in a room (h)

Figure 12 shows a scheme of the used methodology to calculate the ventilation rate.

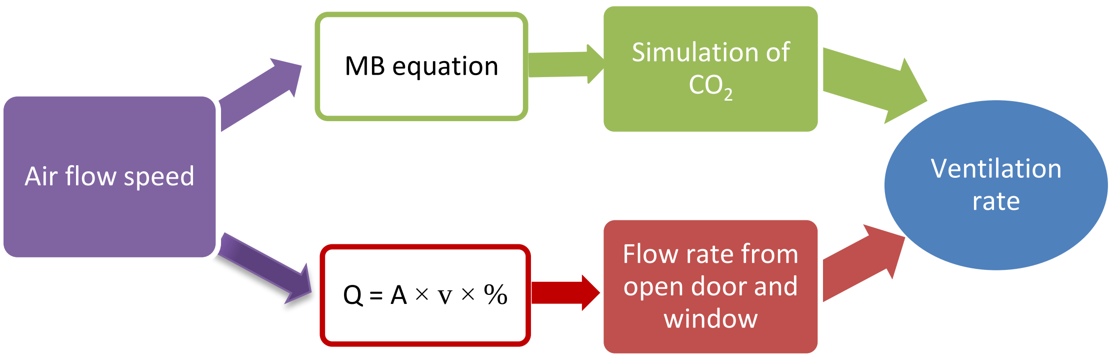


Figure 12: Schematic methodology to determine the ventilation rate.

Estimated CO_2 values are compared with the measured CO_2 values. To obtain similar curves, the value of the air flow speed is set when the estimated and measured CO_2 values overlaps (Figure 14).

5.1.2 Results

The ventilation rate influenced by open door and windows is calculated by using the described methodology (Figure 12). Figure 13 and 14 shows the comparison between hourly measured and estimated CO_2 values from 07h00 to 17h00 along a single day (for a better perception of results).

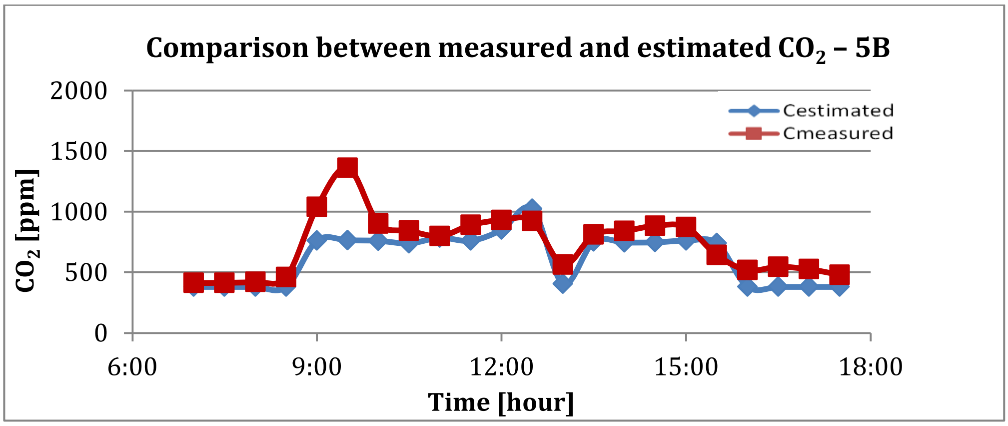


Figure 13: Comparison between the measured and simulated CO_2 concentrations for classroom 5B for 12 June 2013.

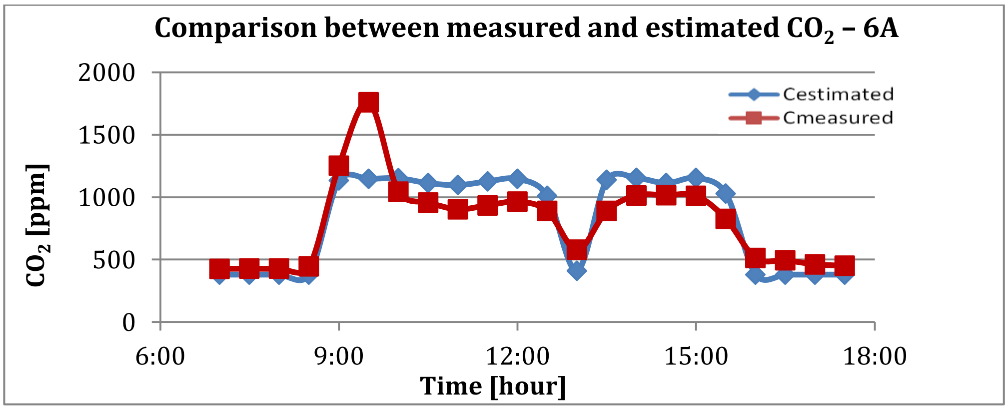


Figure 14: Comparison between the measured and simulated CO_2 concentrations for classroom 6A for 12 June 2013.

The tendency of the curves obtained able to understand the inside activities of the occupants. These results are observed for every single day during the whole monitoring period. The calculation of the ventilation rate (30 min average) is used to determine the resuspension and deposition of PM_{10}, $PM_{2.5}$ and BC.

It is possible to ascertain that the simulated CO_2 concentration generally match with the measured CO_2 concentration. However, the measured CO_2 concentration shows a daily peak at 09h30.

Figure 15 presents daily average measured CO_2 values during the three monitoring periods for the two classrooms. The difference between the two curves is related to the different occupation and activities in the classrooms. Based on this graph it is possible to interpret the deposition and resuspension results.

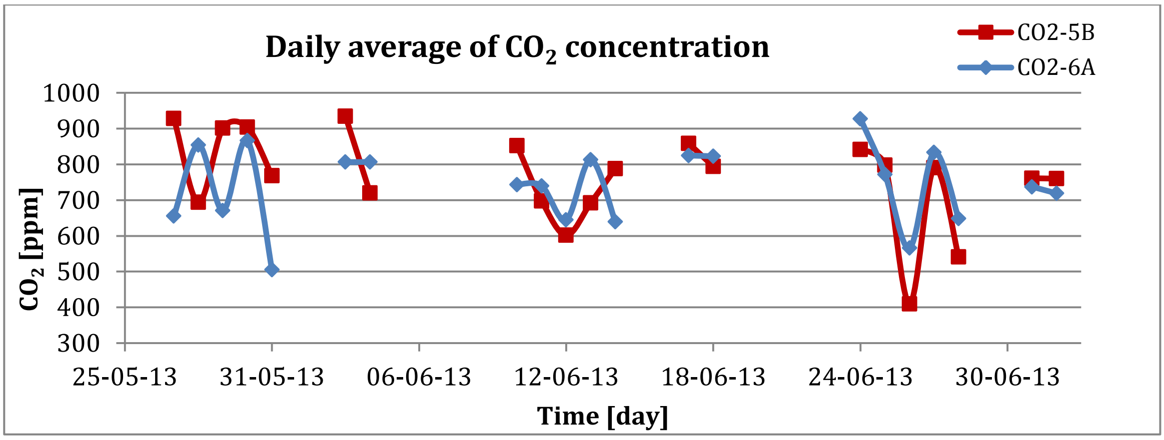


Figure 15: Comparison between the CO_2 concentrations in the classrooms for all monitoring periods.

Figure 16 shows the comparison of the daily ventilation rate values between classroom 5B and 6A. The difference between the behaviour of the occupants in the classrooms is the reason of the variance between the two curves.

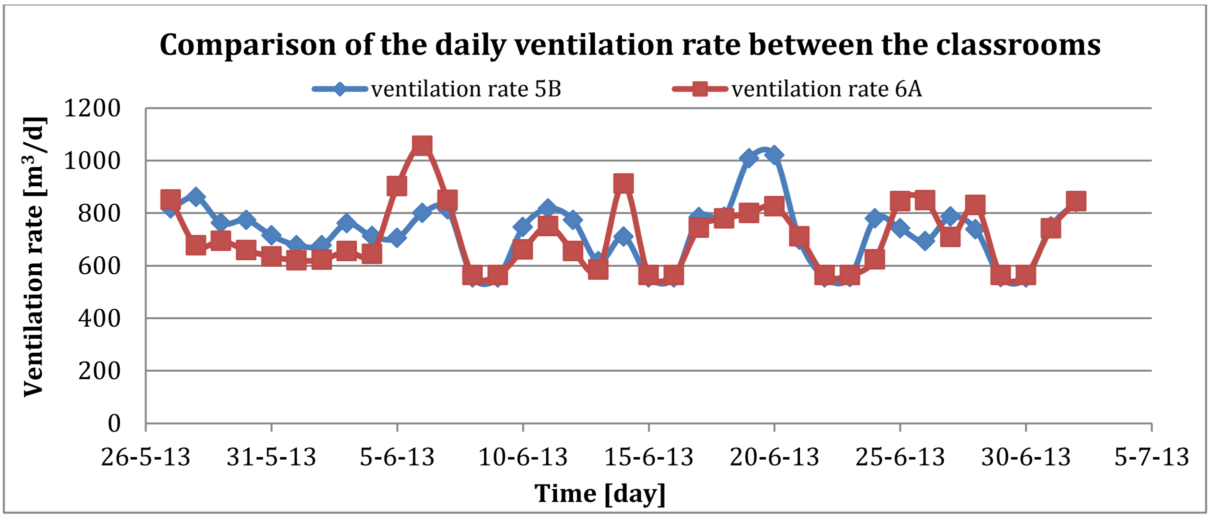


Figure 16: Daily values of the ventilation rate for classroom 5B and 6A.

Because the ventilation rate between the classroom 5B and 6A is not the same (Figure 16), the results of the resuspension and deposition rate will differ.

5.2 Deposition and resuspension

The deposition and resuspension values are calculated, based on the MB equation (eq. 1), for the three monitoring periods.

The classes normally start at 08h00 and finish at 15h00. The resuspension is calculated for the period between 10h00 and 15h00, due to unexplained CO_2 peaks at 09h30. The period considered as deposition starts from at 17h00 and ended at 07h00.

Equations 12 and 13 are used, respectively, to calculate resuspension and deposition levels.

$$\frac{E}{Q} = \frac{C_{in}-C_{out}}{(1-e^{-\frac{t}{\tau}})} \qquad \text{equation 12}$$

$$\frac{D}{Q} = -\frac{C_{in}-C_{out}}{(1-e^{-\frac{t}{\tau}})} \qquad \text{equation 13}$$

Where:

C_{in} – Inside concentration (mg/m^3)

C_{out} – Outside concentration (mg/m^3)

t – Time (h)

E/Q – Resuspension concentration of pollutant (mg/ m^3)

D/Q – Deposition concentration of pollutant (mg/ m^3)

Q – Ventilation rate (m^3/h)

V – Volume (m^3)

τ – Average of air residence in a room (h)

5.2.1 Particulate matter

During the 3rd monitoring period, the APS equipment (which measures the outside concentration of PM) stopped to work. Thus, no outside PM concentrations data are available for the entire monitoring period.

To solve this problem, available outside monitoring values are compared with data from two monitoring stations situated close to the school: The Hague and Schiedam (Figure 3). To determine the reliability of the two stations, the measurements of the first two periods of TNO are compared with The Hague and Schiedam station (Figure 17 and 18). The values presented are the daily averages of the PM_{10} and $PM_{2.5}$ concentrations.

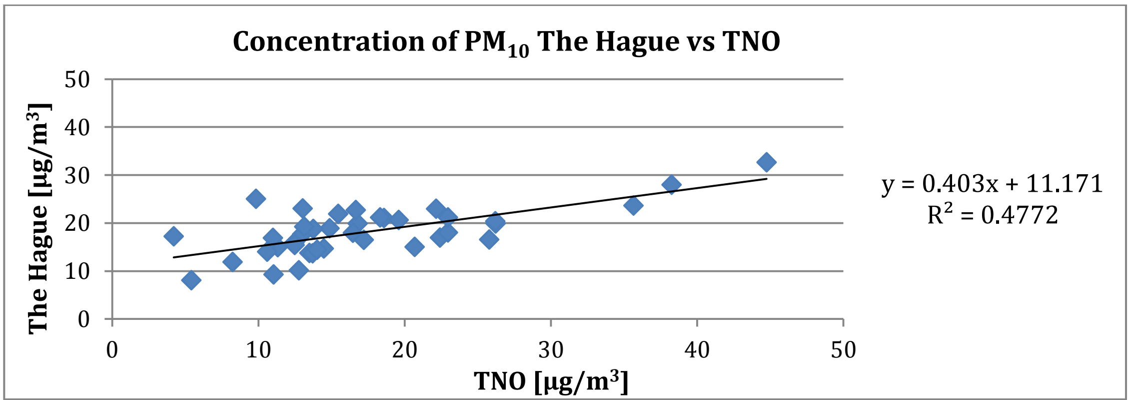


Figure 17: Relationship between PM_{10} concentrations measured at The Hague station and TNO.

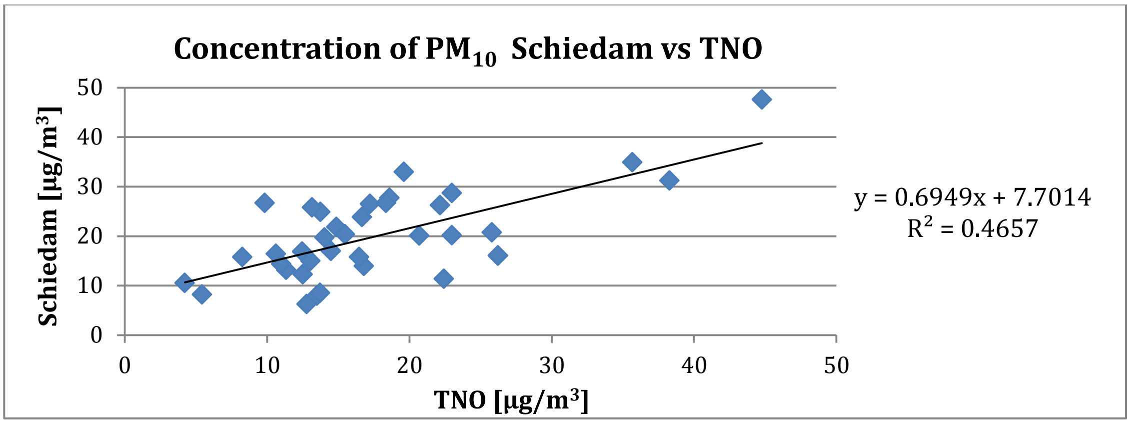


Figure 18: Relationship between PM_{10} concentrations of measured at Schiedam station and TNO.

According to Figure 17 and 18, there is a low correlation between the monitoring stations and the measurements of TNO. Consequently, the selection of the monitoring station is based on the available data. The station of The Hague presented daily data and the station of Schiedam presented hourly data. Therefore, data derived from the Schiedam monitoring station is used as PM outside data for the entire monitoring period.

The results for all periods of the resuspension and deposition of PM_{10} and $PM_{2.5}$ (with and without carpet) are shown in Figure 19 and 20, respectively. The gaps in the graph are caused by the weekends and the carpet change.

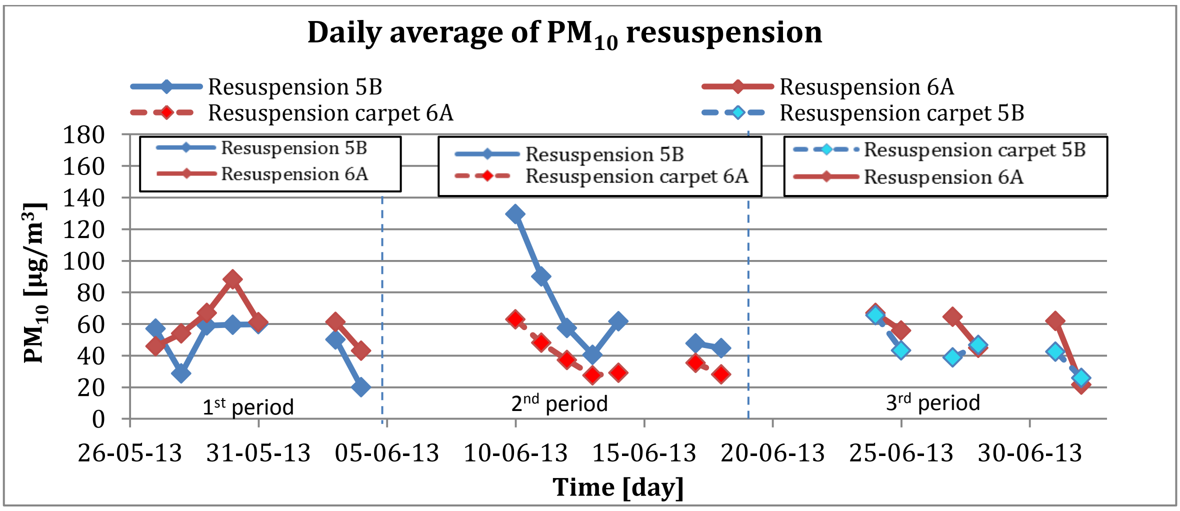


Figure 19: Daily average of the resuspended PM_{10} concentration.

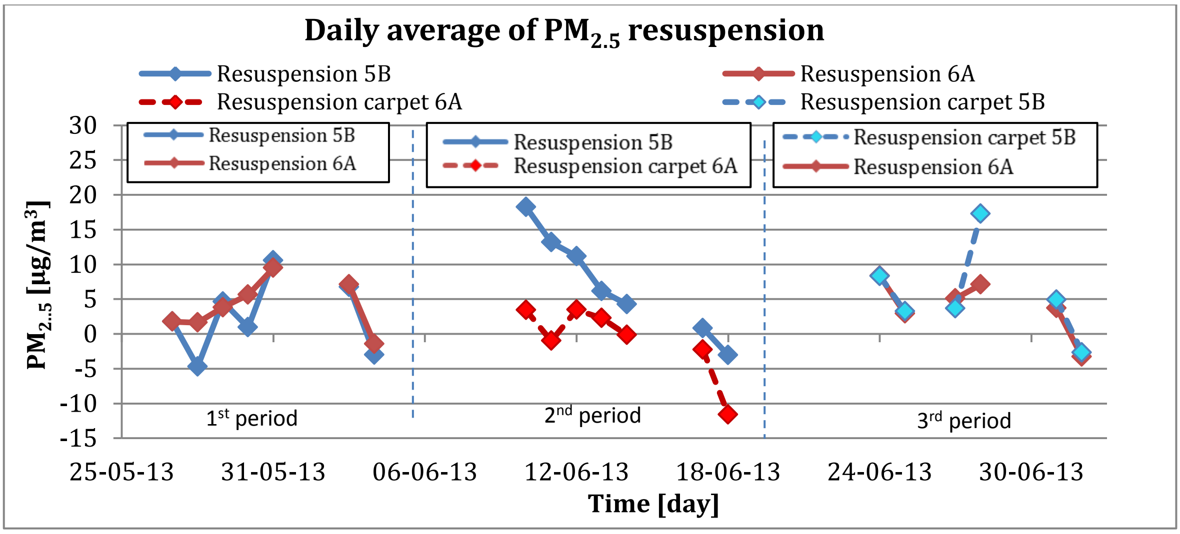


Figure 20: Daily average of the resuspended $PM_{2.5}$ concentration.

The negative values of resuspension shown on Figure 20 represent the deposition.

During the first period (when no carpet was present), the PM_{10} resuspension values in classroom 6A were higher than 5B (Figure 19).

When the carpet was installed in classroom 6A (second period), a clear reduction of resuspension in this classroom is visible. However, the third period does not show this influence of the carpet. The $PM_{2.5}$ measurements show a similar tendency (Figure 20).

The deposition results for PM_{10} and $PM_{2.5}$ are presented in Figure 21 and 22, respectively.

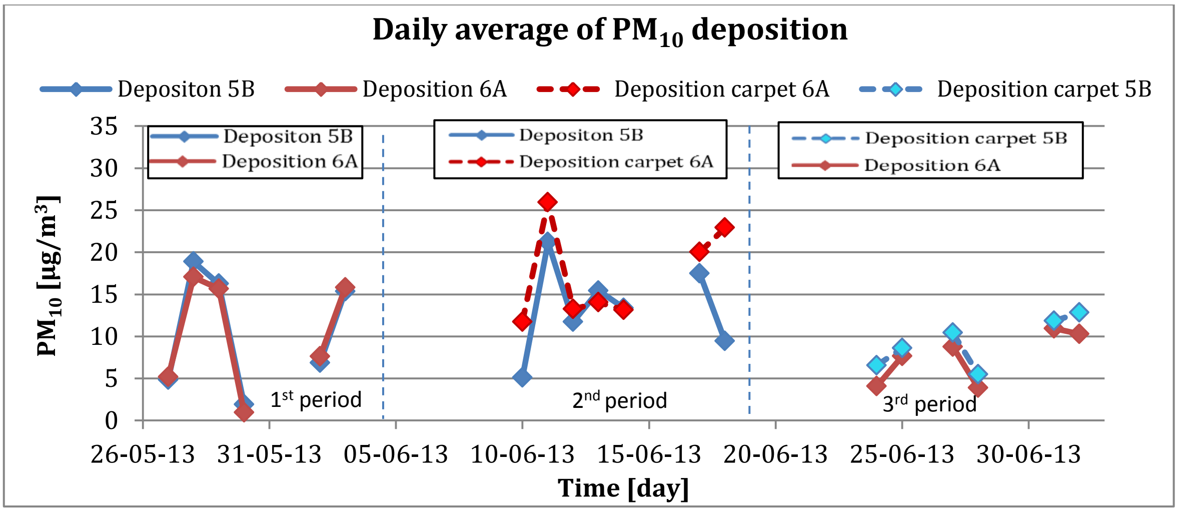


Figure 21: Daily average of the deposited PM_{10} concentration.

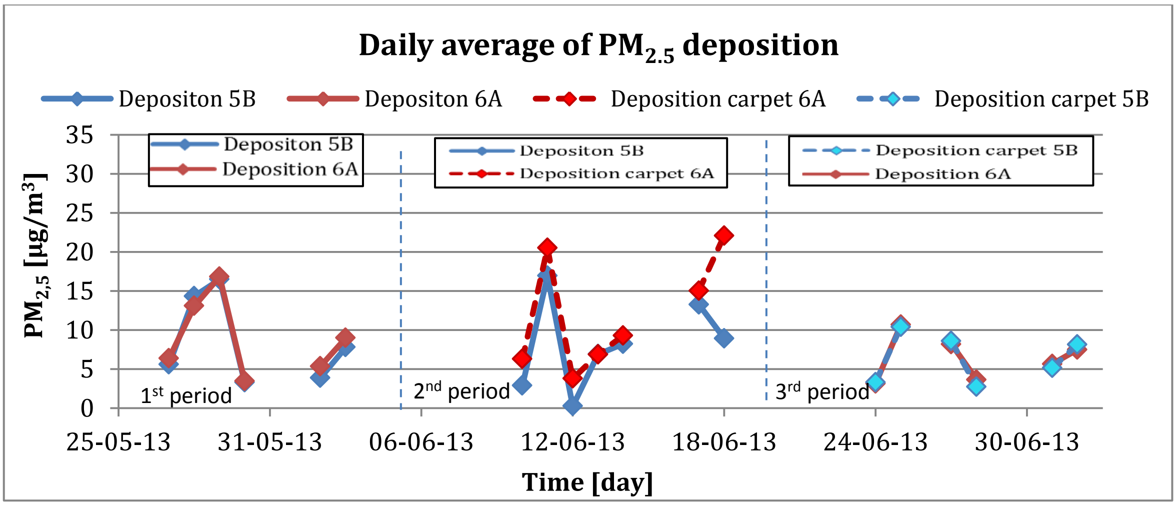


Figure 22: Daily average of the deposited $PM_{2.5}$ concentration.

During the first period (smooth floors), the daily average of PM deposition are practically equal. For the second period (6A has a carpet), the PM deposition values of classroom 6A are higher than 5B. During the third period (5B has a carpet), the PM_{10} deposition values of classroom 5B are higher than 6A. However, the $PM_{2.5}$ values are similar.

As mentioned before, the largest particles sizes are dominated by the gravitational force. Thus the deposition of PM_{10} should be higher than $PM_{2.5}$. This is visible in the data, as shown in Figure 21 and 22.

To have a better perception of the carpet impact on the IAQ, the settling velocity is calculated based on deposition values (eq. 14) for the period between 17h00 and 07h00.

$$v = \frac{C_{dep} \times Q}{3600 \times C_{in} \times A} \qquad \text{equation 14}$$

Where:

v - Velocity settling (m/s)

C_{dep} - Deposition (µg/m³)

Q - Ventilation rate (m³/h)

C_{in} - Inside concentration (µg/m³)

A - Area of classroom (m²)

Figure 23 and 24 presents the settling velocity of PM_{10} and $PM_{2.5}$ in classroom 5B and 6A, respectively.

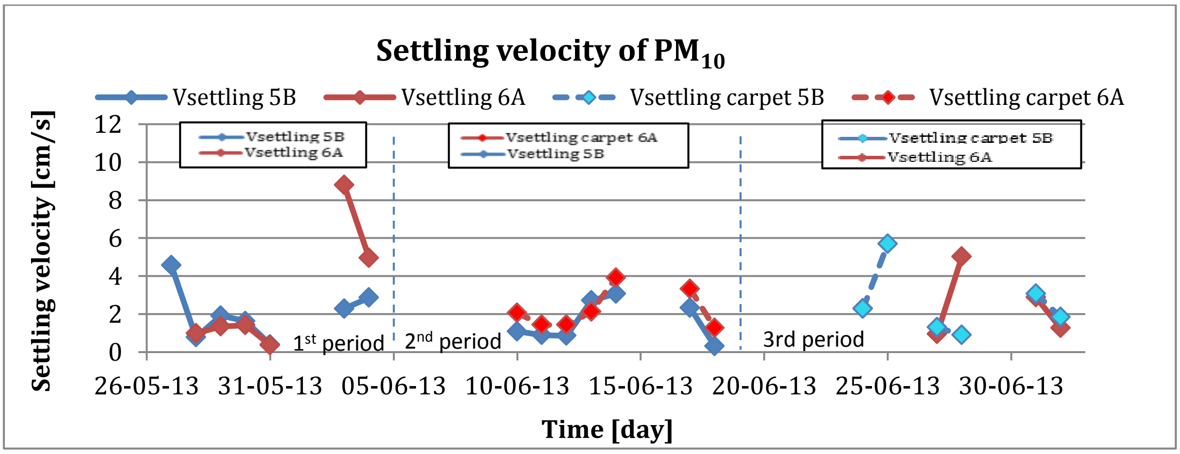


Figure 23: Settling velocity of PM_{10} during the deposition period.

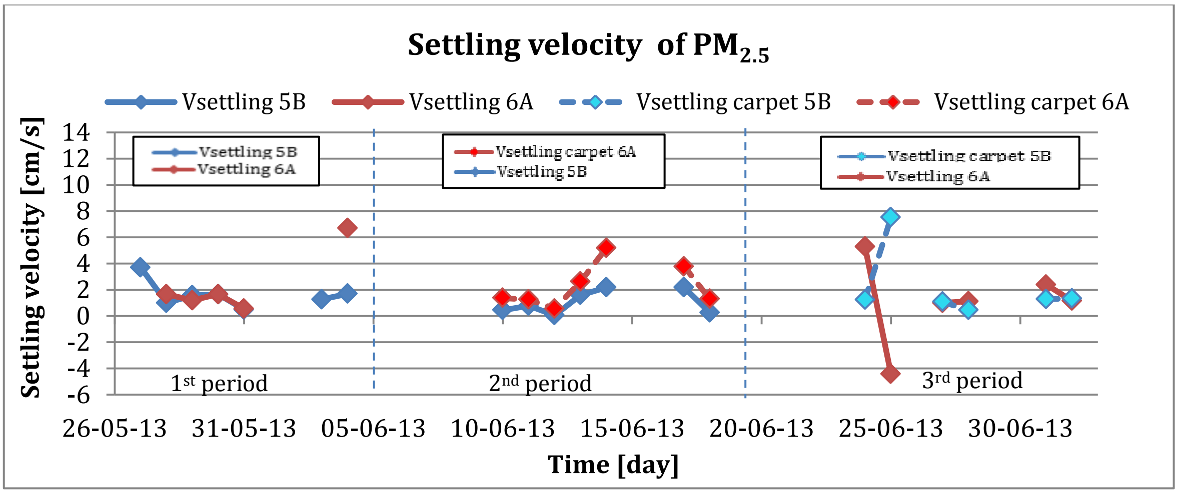


Figure 24: Settling velocity of $PM_{2.5}$ during the deposition period.

The settling velocities for PM_{10} and $PM_{2.5}$ during the first period inside the two classrooms are similar. During the second period, the settling velocities are higher in classroom 6A (with carpet). The results of the third period for PM_{10} show similar or slightly higher settling velocities in classroom 5B (with carpet) comparing to 6A. However, for the third period, $PM_{2.5}$ settling velocity values are not easy to interpret due to the variation.

As mentioned above, the settling velocities of PM_{10} should be higher than $PM_{2.5}$ because of the particle size. However, this does not happen with the calculated values. The measured average settling velocity are much higher than the theoretical values (PM_{10} is 0.3 cm/s and $PM_{2.5}$ is 0.02 cm/s) (Laborde, 2005).

5.3 Black Carbon

To calculate the resuspension and deposition in both classrooms, the outside BC measurements of TNO are used. As for PM, the period of resuspension starts at 10h00 and ends at 15h00. The period of deposition starts at 17h00 and ends at 07h00.

At the end of the third monitoring period (29 June), the equipment which measured the BC inside the classroom 5B stopped to work. Thus, only few BC data is available to compare the classrooms. Figure 25 and 26 presents the resuspension and deposition of BC in ng/m^3, respectively.

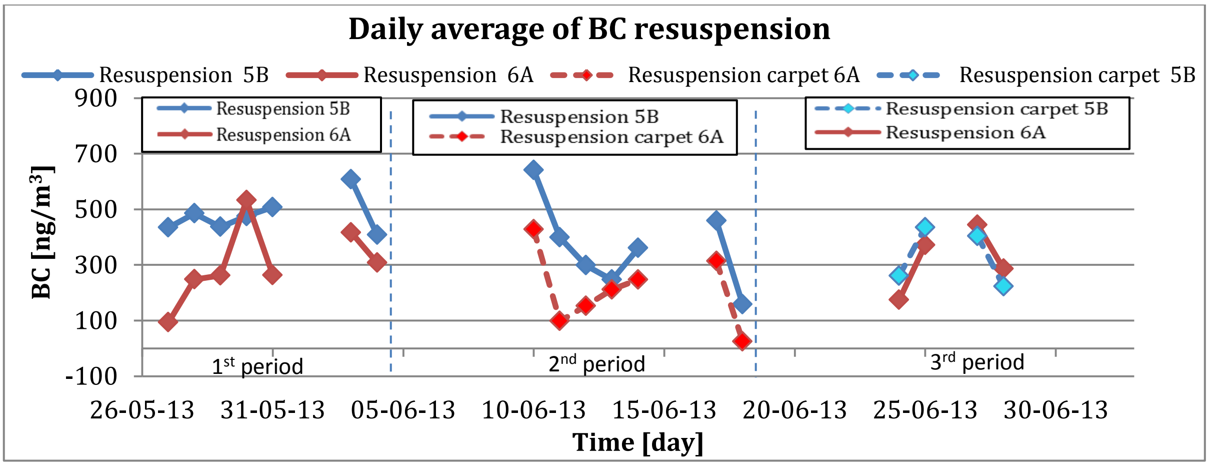


Figure 25: Daily average of the resuspended BC concentration.

During the first period the values of resuspension in classroom 5B are lower than 6A. For the second period, the concentration of the resuspended BC in classroom 6A (with carpet) is lower than 5B. However, when the carpet is present in classroom 5B (third period), the results are not clear: During the first two days of the third period the resuspension in 5B was higher and later the values are lower than 6A (Figure 25).

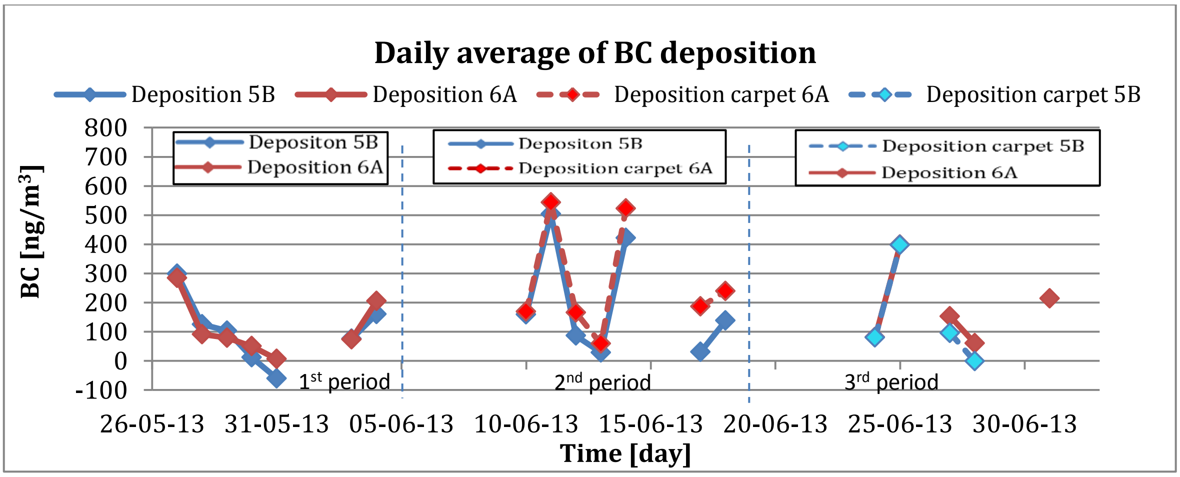


Figure 26: Daily average deposited BC concentration.

During the first period the BC deposition in the classrooms are similar. On 31 June classroom 5B shows a negative value of deposition, indicating resuspension instead of deposition. During the second period, the deposition is slightly higher in the classroom with carpet (6A). The third period shows lower deposition values for classroom 5B (with carpet).

5.4 Relationship between PN, PM and BC

The measurement of PN aims to establish a relation between PM and BC. Figure 27 shows the relation (R^2 >0.97) between the particles larger than 2.5 μm and the PM_{10} concentration. Figure 28 shows the relation (R^2 >0.96) between the number of particles with a diameter between 0.5 and 2.5 μm and the $PM_{2.5}$ concentration.

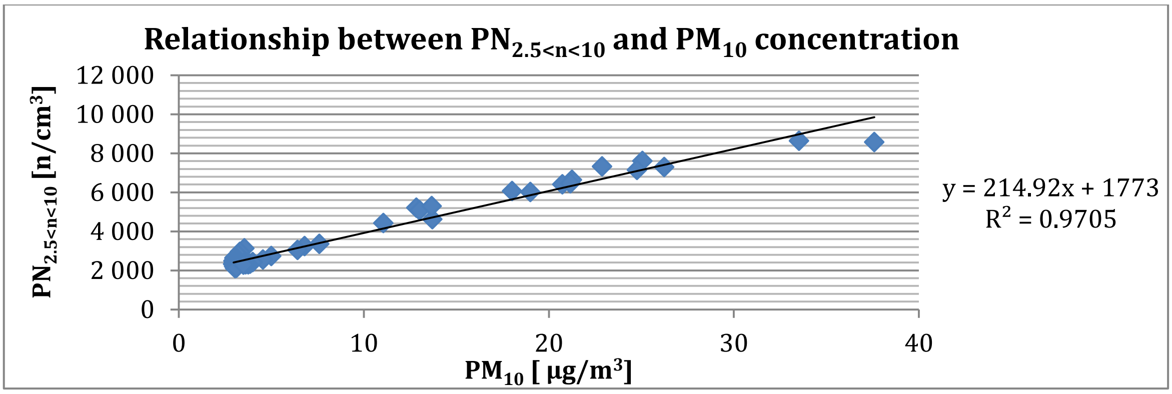


Figure 27: Relationship between $PN_{2.5<n<10}$ and PM_{10} concentration on 28 May.

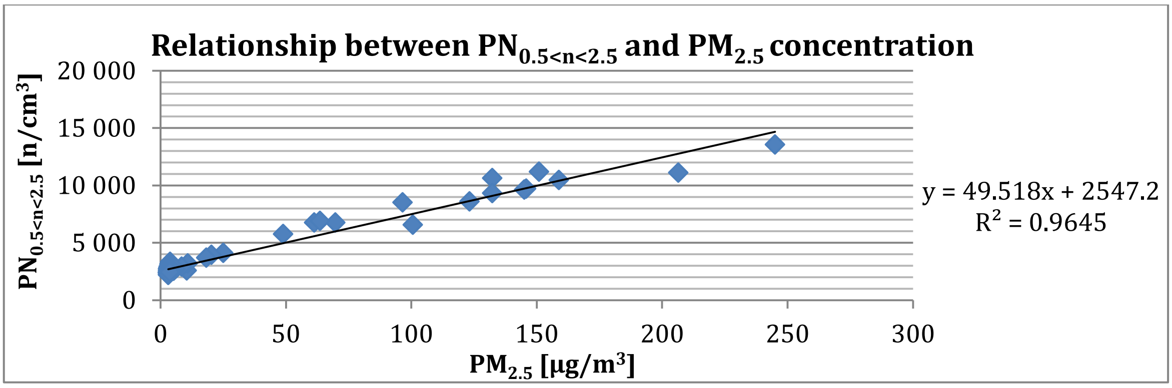


Figure 28: Relationship between $PN_{0.5<n<2.5}$ and $PM_{2.5}$ concentration on 28 May.

During the entire monitoring period, the daily correlation between PN and PM has a coefficient of dertermination (R^2) higher than 0.95. This relation is also applicable to the week measurements.

The comparison between BC and PM are shown in Figure 29 and 30.

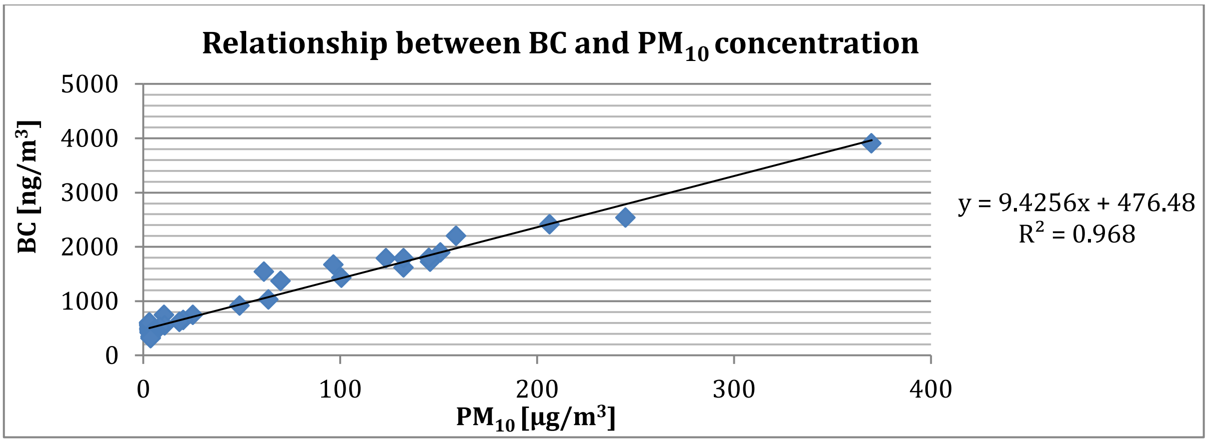


Figure 29: Relationship between BC and PM_{10} concentration on 28 May.

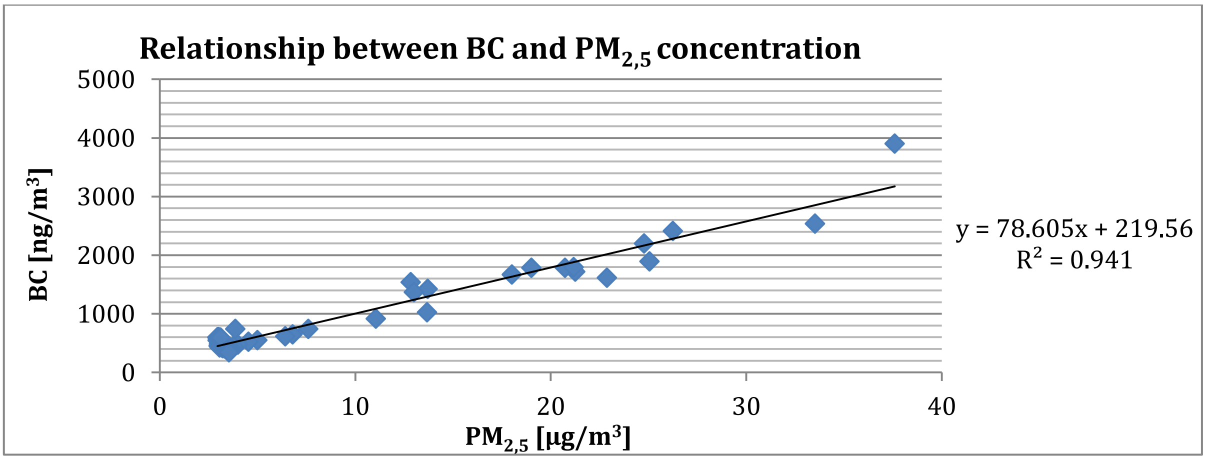


Figure 30: Relationship between BC and $PM_{2.5}$ concentration on 28 May.

The correlation is based on hourly concentration average. For the entire monitoring period R^2 is higher than 0.91 (for BC-PM_{10} and BC-$PM_{2.5}$).

In summary, during the second monitoring period, the resuspension of PM and BC in classroom 6A (with carpet) are lower compared with classroom 5B. The deposition values are higher in classroom 6A than 5B. This suggests that the PM and BC are trapped by the carpet, thus improving the IAQ.

However, during the third period, the oscillation of the resuspension and deposition values (PM and BC) cannot be explained.

Contrary to expectations, the settling velocity values of $PM_{2.5}$ are similar or higher than PM_{10} values. Classroom 6A has higher settling velocities than classroom 5B. Thus, the settling velocity increases when the carpet is present. Nevertheless, during the third period, the values of PM_{10} and $PM_{2.5}$ vary (with and without carpet).

Finally, for this work, there is a clear correlation between PN–PM and BC–PM. This may contribute for additional studies to measure PN (which is cheaper) instead of PM.

6. Conclusion

The main goal of this study is to know the impact of carpet covering floor inside the *Balans* primary school in the Netherlands. The measured pollutants are PM_{10}, $PM_{2.5}$, BC, CO_2 and PN, inside and outside the school. The analyses focus on the deposition and resuspension values of PM and BC. For further studies, a comparison between PN-PM and PM-BC are made to determinate the relation.

Table 11 shows the values obtained for the resuspension, deposition and settling velocities. However, due to some experimental difficulties (e.g. lack of PM outside data at the school) this outcome has to be carefully treated.

Table 11: Summary of resuspension, deposition and settling velocity of PM and BC.

		PM_{10}		$PM_{2,5}$		BC	
		5B	6A	5B	6A	5B	6A
Resuspension	1st period	-	+	-	+	+	-
	2nd period (6A carpet)	+	-	+	-	+	-
	3rd period (5B carpet)	-	+	≈	≈	≈	≈
Deposition	1st period	≈	≈	≈	≈	≈	≈
	2nd period (6A carpet)	-	+	-	+	-	+
	3rd period (5B carpet)	+	-	≈	≈	≈	≈
Settling velocity	1st period	≈	≈	≈	≈		
	2nd period (6A carpet)	-	+	-	+		
	3rd period (5B carpet)	≈	≈	≈	≈		

During the second period, there is a positive effect of the carpet on the IAQ. Classroom 6A (with carpet) shows lower values of resuspension and higher deposition and settling velocity values than 5B. During the third period, the carpet shows an improvement for PM_{10}. However, that does not happen for BC and $PM_{2.5}$ because of the disorganized values.

The behaviour of the occupants in the classrooms influences the IAQ. The ventilation rate values change by opening the doors and windows. Consequently, this affects the resuspension and deposition values which have an impact on the IAQ.

There is a high relation between PN and PM (R^2<0.94). Thus, for further studies Dylos equipment can be used.

As a final conclusion, it is recommended to use the carpet inside the classrooms to improve the IAQ. However, good treatment (i.e. regular cleaning) of the carpet is required.

Limitation and suggestion for future works

The interpretations of the results and conclusions have limitations. To interpret the CO_2 measurements and explain the peak at 09h30, good knowledge of the occupants´ activities is required. Unfortunately, any information is available.

The lack of PM measurements for the third period requires a different data source. Therefore, the Schiedam monitoring station is used. Because Schiedam monitoring station is located relatively far away from the school, the data is less reliable.

For future works related with the carpet effect on IAQ in primary schools, the monitoring period should be longer than 2 month (minimum two complete weeks per period). It would be interesting to see the effect of different carpets.

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